FINAL REPORT

DURIP PROJECT:
Instrumentation for a Temperature Controlled Pulsed-IV Measurement System

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Introduction

In this DURIP project, the Department of Electrical Engineering and Computer Science and the Microsystems Technology Laboratories (MTL) of the Massachusetts Institute of Technology (MIT) requested funds to purchase equipment for advanced RF and microwave device research. The proposed instrumentation enables crucial improvements in our measurement capability through the implementation of a *temperature-controlled pulsed-IV measurement system*. This system includes:

1. A cryogenic probe station to allow on-wafer temperature-controlled DC and RF measurements of electronic devices from 4.2 K to 475 K ($153,715).
2. A dynamic I-V analyzer to characterize transistors and other electronic devices under pulsed, large signal and high power conditions ($120,600).

In this report, we will present the main outcomes of this DURIP project. As it will be shown, the system purchase through this project has significantly improved our capability to measure advanced electronic devices and to understand their operation. Numerous ONR-funded programs are currently benefiting of the advanced measurement capability of the new system. Some examples include the MINE, DRIFT, DEFINE and GATE MURI programs, as well as the ONR Young Faculty Program that the PI received in 2009.

In addition to the numerous results already achieved during the first few months of use of this instrumentation, it is expected than the systems acquired with this project will allow even more outstanding results in the years to come both from MIT and from collaborators.

Summary of acquired equipment

With the $274,315 awarded through this project, the following systems have been bought and successfully integrated in our measurement facility:

- A cryogenic probe station that enables the following:
    - The ability to measure devices at temperatures ranging from 4.2 K to 400 K
    - The ability to perform both DC and RF measurements up to 50 GHz
    - A 2.5 Tesla superconducting magnet, which enables more sophisticated transport measurements in order to better characterize transistor structures
    - The ability to perform measurements under vacuum and also under ambient conditions. Vacuum measurements are very useful for characterizing the breakdown performance of transistors, well as to study the performance of two-dimensional layered materials such as graphene.

Figure 1. Lakeshore cryogenic probe station purchased through this program.

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- A state-of-the-art large signal dispersion and trap measurement system that has been integrated with the cryogenic probe station described before. This system is made of the following components.
  - An Agilent B1505A power semiconductor parameter analyzer.
  - An Agilent N9010A EXA signal analyzer with a bandwidth of 26 GHz.
  - A 20 GHz Agilent N5183A MXG analog microwave signal generator.
  - An Agilent ADSA90604A oscilloscope with a 6 GHz bandwidth. This oscilloscope is used for the pulsed-IV measurements.

In addition to the equipment needed to build the advanced temperature-controlled pulsed-IV system, we have also purchased a state-of-the-art rapid thermal annealing system with NH_3 capability, which is key for our current work on the development of implantation technology for InAlN/GaN high frequency devices.

All these systems have been integrated in the *Center for Advanced Electron Devices and Sensors* at MIT. As we will see in the "*results*" section of this report, these new measurement capabilities have already allowed the characterization of record performance in novel devices as well as a better understanding of the pulsed and large signal behavior at gigahertz frequencies.

Main Scientific Results of the Project

The instrumentation acquired through this project has been essential to characterize the dispersion and trap behavior of devices fabricated both by MIT and different partner companies (e.g. TriQuint Semiconductors). In the last 4 months, a better understanding of dispersion has been achieved thanks to pulsed-IV measurements under cryogenic temperatures and vacuum conditions. Due to the relevance of all these results, numerous scientific papers and conference contributions have already been presented. Some of them are summarized below and in the papers that follow. Also, the improved measurement capability is expected to be extremely important during the development of the MINE, DEFINE and DRIFT, and GATE MURI projects.

Partial list of scientific papers and conference contributions that are based on measurements performed by equipment acquired through this DURIP project:

- D. S. Lee, J. W. Chung, H. Wang, X. Gao, S. Guo, P. Fay, and T. Palacios, "245 GHz InAlN/GaN HEMTs with Oxygen Plasma Treatment," Submitted to IEEE Electron Device Letters, Dec. 2010.

- H. Wang, A. Hsu, K.K. Kim, J. Kong and T. Palacios, "Gigahertz Ambipolar Frequency Multiplier Based on CVD Graphene," International Electron Devices Meeting (IEDM) 2010, San Francisco, CA Dec 2010

- D.S. Lee, M. Connor, C. Hatem, X. Guo and T. Palacios: "Ultra-low Contact Resistance in InAlN/GaN Heterostructures Through Si ion Implantation,"

International Workshop on Nitride Semiconductors (IWN), Tampa, FL, Oct. 2010.

- O.I. Saadat, K.K. Ryu, Y. Liu, R.G. Gordon and T. Palacios: “Low-k passsivation layers for AlGaN/GaN HEMTs”. International Workshop on Nitride Semiconductors (IWN), Tampa, FL, Oct. 2010.

- H. Wang, A. Hsu, K.K. Kim, J. Kong and T. Palacios “Graphene Ambipolar Electronics” International Symposium on Graphene Device (ISGD) 2010, Sendai, Japan, Oct 2010.

- H. Wang, A. Hsu, J. Wu, J. Kong and T. Palacios “Graphene-Based Ambipolar RF Mixers” IEEE Electron Device Letters, Vol. 31, No. 9, 2010.

- H. Wang, A. Hsu, K.K. Kim, J. Kong and T. Palacios “Graphene Ambipolar Electronics” Graphene Week 2010, Maryland, April 2010.

- B. Lu and T. Palacios, “*High Breakdown (> 1500 V) AlGaN/GaN HEMTs by Substrate-Transfer Technology*” IEEE Electron Device Letters, Vol. 31, No. 9, pp. 951-953, Sept. 2010.